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AERODYNAMIC TESTS OF A LOW ASPECT RATIO TAPERED WING  
WITH AN AUXILIARY AIRFOIL FOR USE ON TAILLESS AIRPLANES

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FOR REFERENCE

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### AERODYNAMIC TESTS OF A LOW ASPECT RATIO TAPERED WING WITH AN AUXILIARY AIRFOIL FOR USE ON TAILLESS AIRPLANES

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#### SUMMARY

Wind-tunnel tests were made of a model wing having an aspect ratio of 3, a tapered plan form with a straight trailing edge, and a fixed auxiliary airfoil of constant chord. Trimming moments were obtained through the upward deflection of a full-span, constant chord trailing-edge flap.

Lift and drag comparisons were based upon flap settings that would trim the model with the center of gravity placed as far back as possible without producing instability in the airplane under any conditions of level flight.

The auxiliary airfoil increased the maximum lift of the model about the same percentage as it increased the drag for high-speed flight over that of the model without the auxiliary airfoil. The lift obtained in the trimmed condition with the auxiliary airfoil compares favorably with that for a conventional airplane.

The improvement of the model obtained through the application of the auxiliary airfoil in the position tested was not sufficient to justify the necessary complication.

#### INTRODUCTION

An airplane in which the power plant, the cargo space, and the control and stabilizing surfaces are all included in the wing is an ideal of aerodynamic efficiency that has been sought by many designers. Experiments during the past forty years by Dunne, Lippisch, Hill, and others (references 1 to 7, inclusive) on tailless airplanes have been in this direction with results that have appeared successful at the time, but no real use has ever been made of tail-

less airplanes. Previous work at the Laboratory (reference 7) has shown that a low aspect ratio wing with decided taper gives promise of being as adaptable to the use of a tailless airplane as the higher aspect ratio wings with less taper, which have been used by most of the earlier experimenters. It would seem, from tests on rectangular wings (reference 8), that the addition of a leading-edge auxiliary airfoil to the wing would give a higher lift coefficient with the flaps set to trim.

The present report gives the results of tests made on a tapered wing with a nontapered auxiliary airfoil affixed to it. The wing was the one used in reference 7. The locations giving the highest value of  $C_{Lmax}^a/C_{Dmin}$  for the chord ratios at seven points along the span of the tapered wing were determined from the tests of auxiliary airfoils of various chords (reference 8), and the auxiliary airfoil was bent and set to lie as close to these positions as possible. (See table I.) The tests were limited to the one combination of wing and auxiliary airfoil and to the one position.

Upward deflection of the full-span plain flap was used to obtain trim at various angles of attack, since this flap was shown to be the best in previous tests of this model.

#### APPARATUS

Wind tunnel.— The tests were made in the N.A.C.A. 7 by 10 foot wind tunnel, which is described in detail in reference 9. They were made at a dynamic pressure of 16.37 pounds per square foot, which corresponds to an air speed of 80 miles per hour at standard sea-level conditions. The Reynolds Number for this speed is 933,000, based on the mean aerodynamic chord of the main wing, which is defined as the chord at the centroid of the semiwing (reference 10).

Model.— The model (fig. 1) consisted of a laminated mahogany main wing and an aluminum-alloy auxiliary airfoil mounted ahead and above it by seven thin steel brackets attached to the ends and lower surfaces of the two airfoils. The main wing had a span of 42.43 inches and an aspect ratio of 3. It had a 3:1 taper, the chord at the center being 21.21 inches and that at the tip being 7.07 inches. The Clark Y section was used over the entire span as the basic section - with the flaps neutral. All the

upper extremities of the maximum ordinates of the upper surface were located in a plane parallel to the chord line of the root section, giving the wing a certain dihedral angle. The flap was hinged parallel to the trailing edge. It had a constant chord which was one half the wing chord at the tip and one sixth the wing chord at the center, making its area one fourth the total wing area. The gap between the flap and the main portion of the wing was sealed with Plasticine for each test, and the V cut between the flap sections at the center, which was necessary to permit their upward deflection, was covered with adhesive paper.

The auxiliary airfoil consisted of two parts fastened together at the center line of the wing. The sections through them at right angles to the leading edge were N.A.C.A. 22 with a 1.45-inch chord (see table II) but, since the leading edges were at an angle of approximately  $37^\circ$  with the lateral axis of the main wing, the effective airfoil section was much elongated from this contour and had a chord of 1.805 inches, measured in a plane parallel with the tunnel axis.

An attempt was made to locate the auxiliary at each mounting bracket so that it was in the optimum position for the particular ratio of auxiliary airfoil chord to main wing chord at that point on the span. The position which the auxiliary finally took after having been bent and twisted into shape is given in table I. The values are the average ones for the two sides. These locations are probably closer to the optimum positions, as computed from reference 8, than this position is to the true optimum for such a tapered wing. Although the angle of the auxiliary airfoil at all points is less than was desired, it could not be changed without throwing the trailing edge out of position at two supports.

## TESTS

Tests were made to find the lift, drag, and center of pressure of the combination with the flaps set upward at various angles. A test was also made with the flaps set at  $5^\circ$  and with the fittings in place without the auxiliary airfoil. The difference between the drag in this test and that in a test without fittings at the angle of attack for

minimum drag was 0.0010 when converted to the coefficient for the wing with auxiliary airfoil. This value was assumed equal to the drag of the fittings with the airfoil in place and was subtracted from all drag readings. No corrections were made for tunnel-wall interference. Lift and center-of-pressure effects of the fittings were assumed to be within the limits of accuracy for the tests and were therefore neglected.

## RESULTS

The lift and drag, based on the total area of the two airfoils, and the center of pressure, based on the mean aerodynamic chord of the main wing, as previously described, have been plotted in figure 2 against the angle of attack. The center-of-pressure curves indicate that at some flap angle between  $4^\circ$  and  $5^\circ$  up the wing will be neutrally stable with the center of pressure at about 21 percent of the mean aerodynamic chord from its leading edge. The center of gravity of the airplane was therefore assumed to be at 21 percent, and a cross plot (fig. 3) was drawn so that the lift and drag at each angle of attack are given for the flap angle necessary to trim the airplane at that angle. The flap angle  $\delta_f$  is also plotted against angle of attack. In order to facilitate comparisons, similar curves for the plain model, taken from reference 7, have been included in figure 3.

## DISCUSSION

The maximum lift coefficient reached with the auxiliary airfoil attached to the wing and with the flap neutral was 1.52, a 10 percent gain over 1.38, the value obtained with the plain wing. The maximum lift coefficient at trim with the auxiliary airfoil, however, was 1.32, or 24.2 percent higher than that of the same wing without the auxiliary airfoil. Although these values seem to indicate that a large percentage of the lift coefficient is sacrificed to obtain trim at the stall ( $1.52 - 1.32 = 0.20 = 13.3 \text{ percent} \times 1.52$ ), it must be noted that in a normal airplane the down-load on the elevators reduces the effective over-all lift. (The Fairchild F-22 with an N-22 wing has a maximum lift coefficient of 1.48, based on the wing area, with the tail at  $0^\circ$  to the thrust line and only 1.31,

or 11.5 percent less with the tail set to trim.) (See reference 11.)

The minimum drag recorded for the wing with the auxiliary airfoil was 0.016; this was at  $\alpha = -2^\circ$  with the flap turned upward  $5^\circ$ . The drag of the wing without an auxiliary airfoil was a minimum (0.012) at  $\alpha = 2^\circ$  with the flap turned upward  $15^\circ$ . Since these are not trim conditions for either case, it is better to compare them on another basis. The high-speed lift coefficient for a speed-range ratio of 3 was calculated and the drag for the wing trimmed to fly at this coefficient was found. The drag coefficient in this condition was 0.017 for the wing with the auxiliary airfoil and 0.014 for the plain wing. These coefficients give a ratio of maximum lift to drag at high speed of 76.5 for the wing with the auxiliary airfoil and 77.2 for the plain wing. The  $C_{L_{max}}^2$  divided by the above drag coefficients of the trimmed conditions are, however, 99.3 and 83.3 for the two cases. Although this criterion indicates a small advantage for the auxiliary airfoil, the reduction in size permissible with the higher lift coefficient does not seem to compensate for the loss of climb and the complication of adding the auxiliary airfoil, unless a more suitable location be found for it.

The angle for maximum lift of the present arrangement is  $29^\circ$ , which is much higher than for conventional airplanes and  $7^\circ$  higher than for the plain tailless model. This condition requires special considerations for landing and taking off at the maximum lift coefficient. A glide-in landing allows a landing at the proper angle with a long-travel, but not unusually high, landing gear; a take-off, however, requires the attainment of a large angle with respect to the ground. The obvious solution is to take off at a speed above the minimum. Since the lift coefficient of the wing with the auxiliary is higher than for the plain wing near the stall of the latter, the take-off speed would be less, at any given angle, with the former than with the latter for the same wing loading. The objection is therefore no more pertinent to the arrangement under consideration than to the plain tailless airplane of low aspect ratio.

The value of  $L/D$  at  $C_L = 0.7$ , which is an indication of the effectiveness of the wing in climbing flight, is very low (6.1) for the tailless airplane with the auxiliary airfoil and not very high (8.75) for the plain one.

This factor is the greatest detriment for a low aspect ratio wing and for a wing with an auxiliary airfoil as well. The span loading must therefore be kept low to obtain a reasonable climb. This requirement, of course, means a low wing loading if the aspect ratio is fixed.

### CONCLUSIONS

1. The maximum lift coefficient of the tailless airplane model tested is substantially greater with the auxiliary airfoil than without it, and is equal to that of a conventional airplane.
2. The minimum drag of the model is increased by the application of the auxiliary airfoil so that the advantage of this device in the position tested is negligible.
3. Tests involving the movement of the auxiliary airfoil for the longitudinal control of a tailless airplane are recommended.

Langley Memorial Aeronautical Laboratory,  
National Advisory Committee for Aeronautics,  
Langley Field, Va., November 7, 1933.

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TABLE I

LOCATION OF TRAILING EDGE AND ANGLE OF CHORD OF

AUXILIARY AIRFOIL WITH RESPECT TO MAIN WING

Chord length of auxiliary airfoil is 1.805 inches

Percent span from center	Chord* length, inches	Percent c* above chord	Percent c* ahead of L.E.	Angle** with chord degrees
0	21.21	4.37	14.43	-3-3/4
14.2	17.18	8.95	14.76	2
33.1	11.84	13.31	16.26	- 3/4
50.0	7.07	10.91	19.25	1-1/2

\*Chord of main wing at given span location.

\*\*Positive angle indicates angle of attack of auxiliary airfoil is greater than that of main wing.

TABLE II  
AIRFOIL ORDINATES

(All values given in percent of chord)

Clark Y			N.A.C.A. 22 (Section perpendicular to L.E.)		
Station	Upper surface	Lower surface	Station	Upper surface	Lower surface
0	3.50	3.50	0	2.88	2.88
1.25	5.45	1.93	1.25	5.40	1.09
2.5	6.50	1.47	2.50	6.48	.65
5	7.90	.93	5	8.02	.28
7.5	8.85	.63	7.5	9.11	.08
10	9.60	.42	10	9.96	.00
15	10.69	.15	15	11.34	.12
20	11.36	.03	20	12.29	.44
30	11.70	.00	30	13.35	1.46
40	11.40	.00	40	13.42	3.08
50	10.52	.00	50	12.60	4.78
60	9.15	.00	60	11.12	5.63
70	7.35	.00	70	9.15	5.79
80	5.22	.00	80	6.68	4.68
90	2.80	.00	90	3.95	2.67
95	1.49	.00	95	2.51	1.32
100	.12	.00	100	1.13	.00

L.E. radius = 1.50

L.E. radius = 2.00

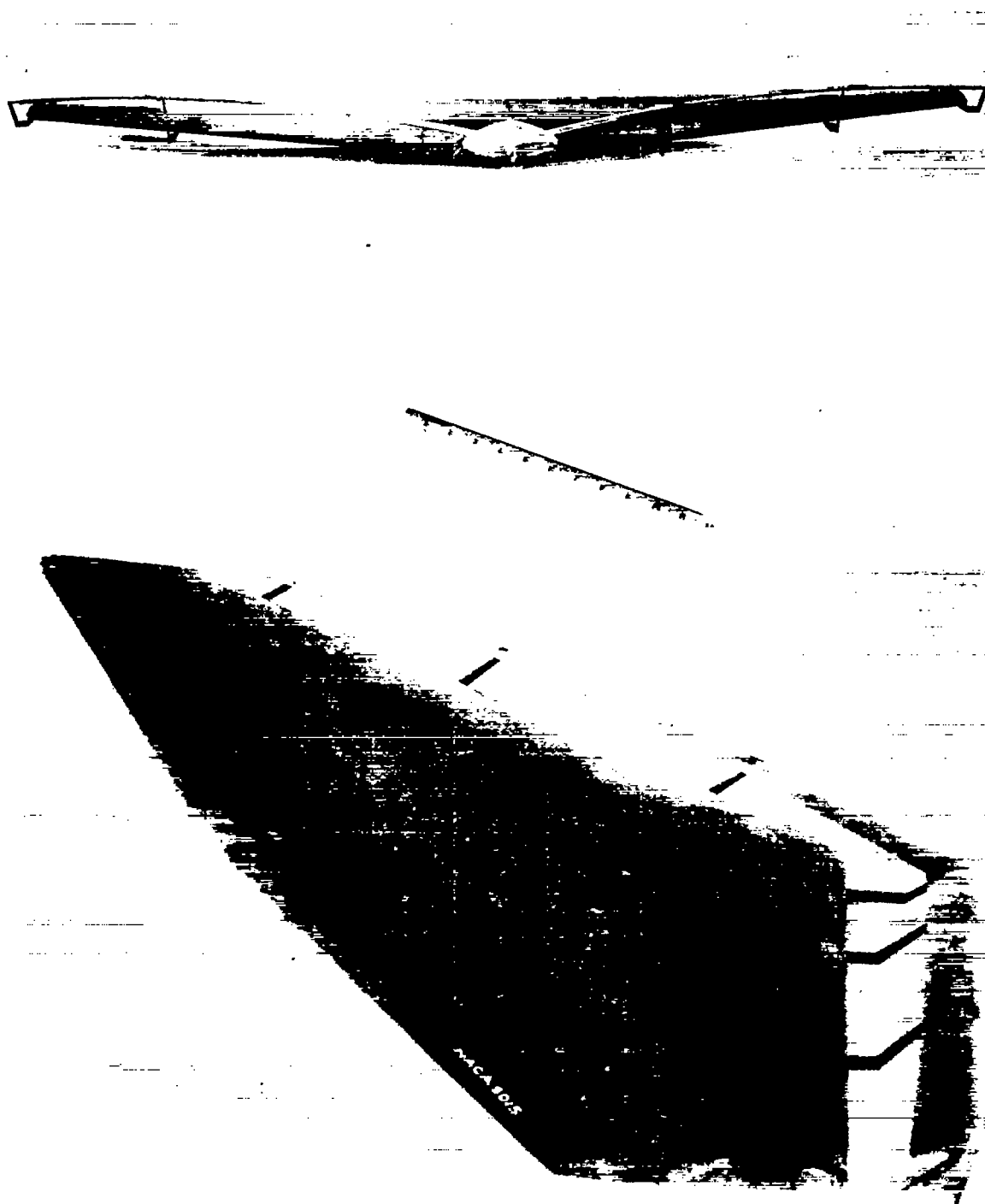
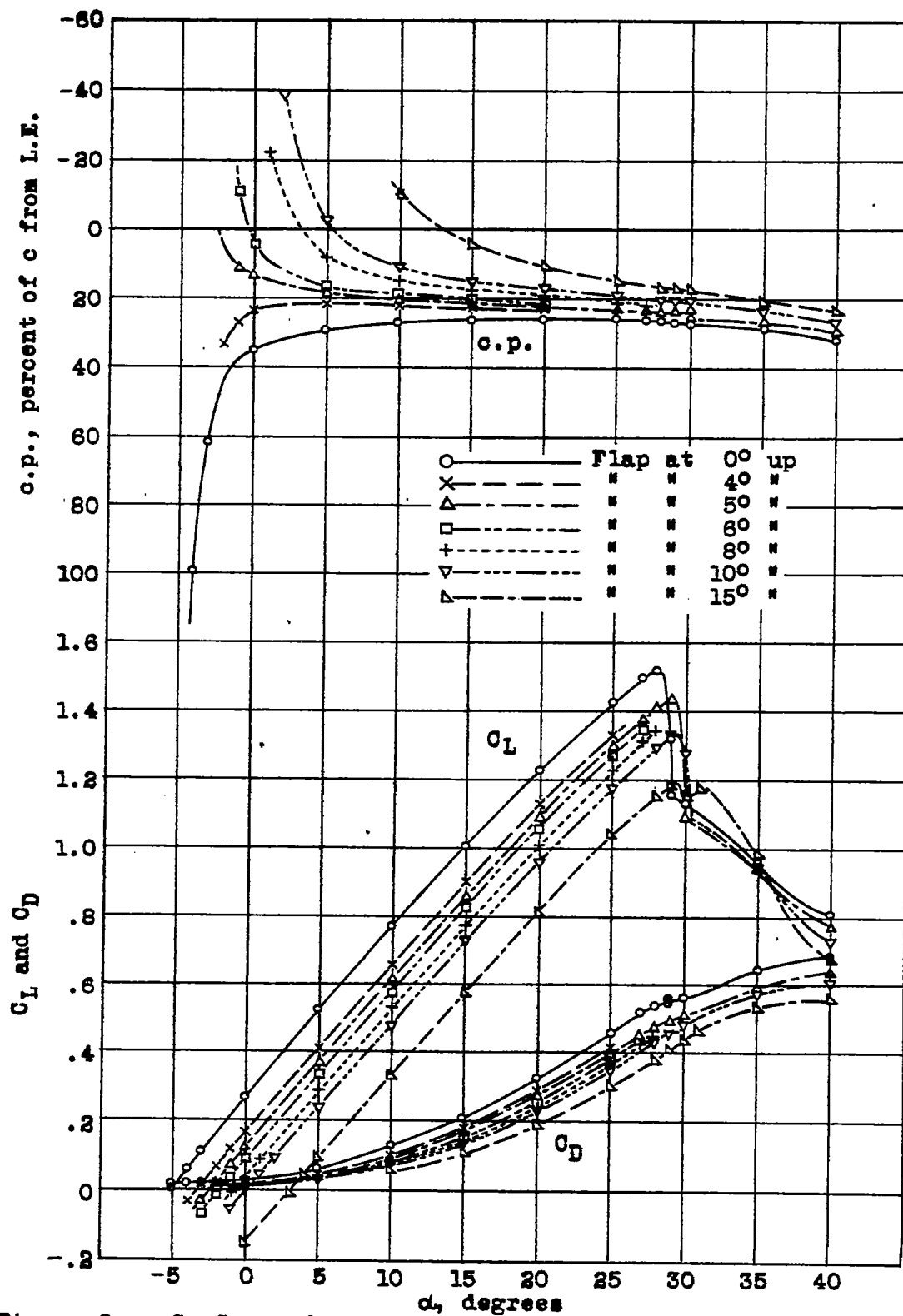
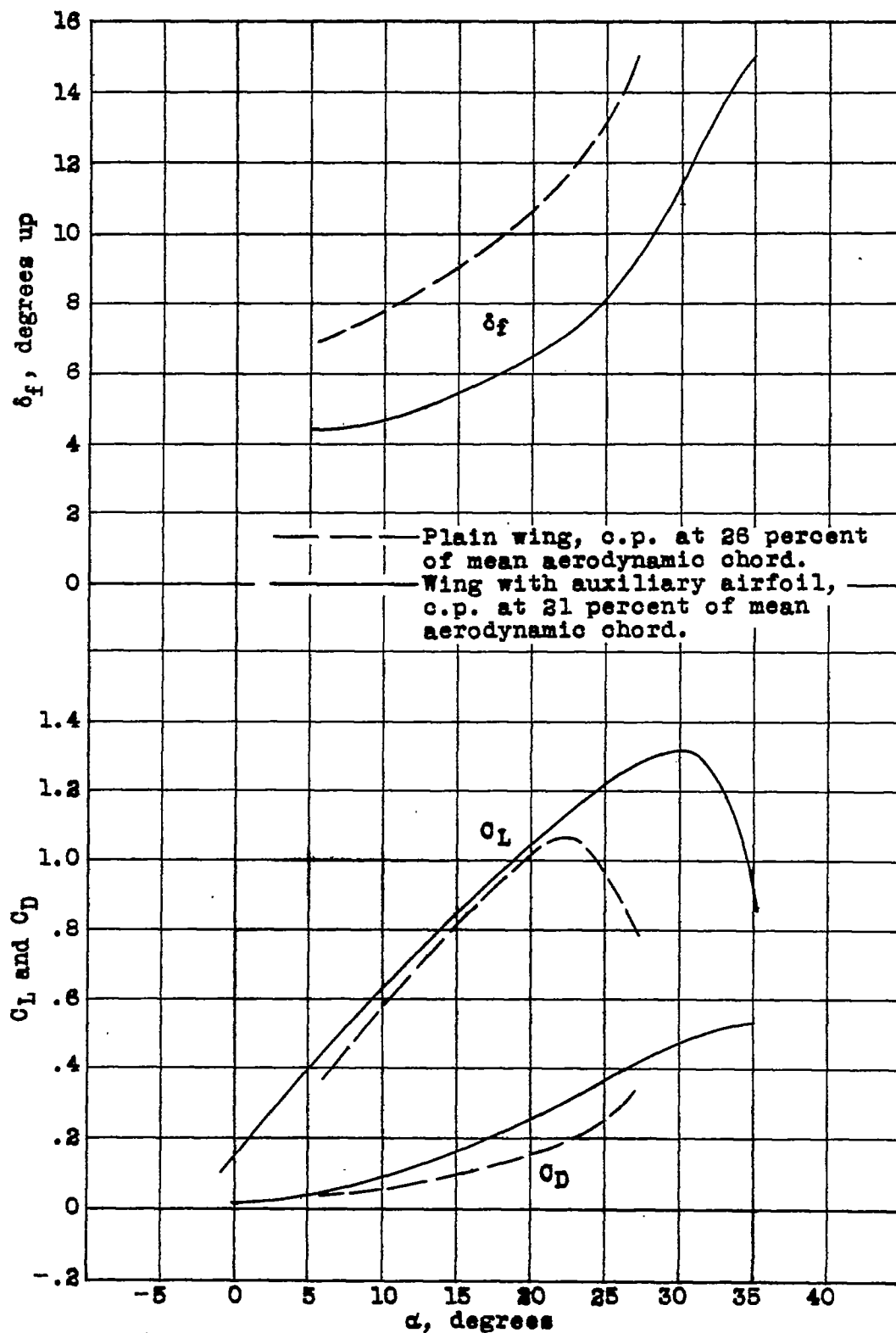


Figure 1.- Model of tapered wing with auxiliary airfoil.


Figure 2.-  $C_L$ ,  $C_D$ , and c.p. with flap set at various angles

Figure 3.—  $C_L$ ,  $C_D$ , and  $\delta_f$  for a constant c.p.